All-metal Dual Frequency RHCP High Gain Antenna for the Extreme Environments of a Potential Europa Lander

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***Abstract*— A new all-metal dual-frequency RHCP high gain antenna is under development at NASA's Jet Propulsion Laboratory for a potential Europa Lander. The antenna is mainly made of metal so it could survive the harsh environment conditions (i.e. very low temperature and high radiation and ESD levels). The antenna is also flat to meet drastic volume constraints and has efficiencies higher than 80% at both the uplink and downlink X-band Deep Space frequency bands. This antenna is a key component for the potential mission enabling Direct Link to Earth (DTE) from and Direct-from-Earth (DFE) to the lander without any relay.**

***Index Terms*—antenna, array, stripline, waveguide, dual frequency, DTE, DFE, telecommunication, patch.**

I. Introduction

Europa Lander is a proposed NASA astrobiology concept mission that would place a lander on Europa, a moon of Jupiter which is thought to have a liquid ocean under its icy surface as well as water plumes. If selected and developed, the Europa Lander would be launched in 2025 to complement the science undertaken by the Europa Clipper mission. The objectives of the Europa Lander would be to search for biosignatures at the subsurface, to characterize the composition of non-ice near-subsurface material, and determine the proximity of liquid water and recently erupted material near the lander's location [1].

For telecommunication, the Europa Lander Project is exploring the possibility of relying solely on communication with Earth, Direct-to-Earth (DTE) and Direct-from-Earth (DFE) rather than relaying signals via a nearby spacecraft. This would require a large antenna aperture and a high transmitter power of at least 100W. The antenna must operate well at both the uplink (7.145-7.190 GHz) and downlink (8.40-8.45GHz) Deep Space frequency bands and must handle up to 100 W of input power in a vacuum.

The Europan environment presents extreme challenges due to its high radiation and ESD levels and ultra-low temperatures. In addition to these severe environment conditions, there are tight volume constraints forcing the antenna to be completely flat and limiting its size. To withstand the harsh temperature conditions and radiation levels, the antenna should be made mainly of metal.

The maximum aperture area that would be available is 82.5cm × 82.5cm and therefore, very high efficiency (>80%) is required to close the link from Europa. Several antennas,

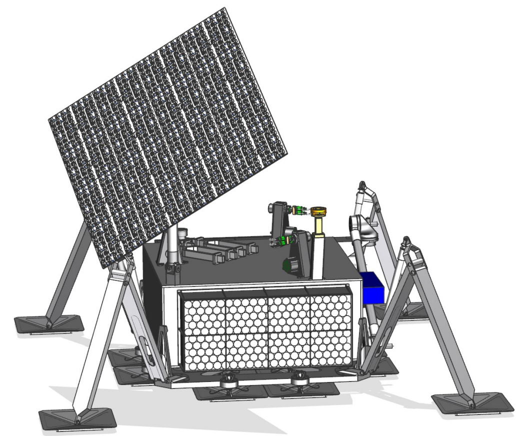


Fig. 1. An artist's concept of a potential Europa Lander with the all-metal dual-frequency RHCP HGA for DTE / DFE.

such as RLSA [2] or metasurface antennas [3],[4], were initially considered but found not to meet the high efficiency requirements at both frequencies.

Researchers have investigated different approaches to obtain dual-band or wideband performance in CP patch antennas, including stacked patch antennas [5], slotted patch shapes, slotted ground planes [6], E-shaped [7], U-slot [8], L-shaped [9], and so on. None of the aforementioned solutions are compatible with all-metal solutions that could potentially scaled to a very large array.

NASA's Jet Propulsion Laboratory is developing a new type of all-metal RHCP patch array with the potential of demonstrating more than 80% efficiency at both uplink and downlink frequencies. The dual-frequency RHCP antenna will leverage construction methods developed for the Juno MicroWave Radiometer single-frequency linearly polarized patch array antennas [10]. We strongly believe that the proposed all metal dual-band RHCP high gain antenna will pave the way for the next generation of Deep Space DTE/DFE antennas enabling revolutionary new concepts for space exploration in harsh environments.

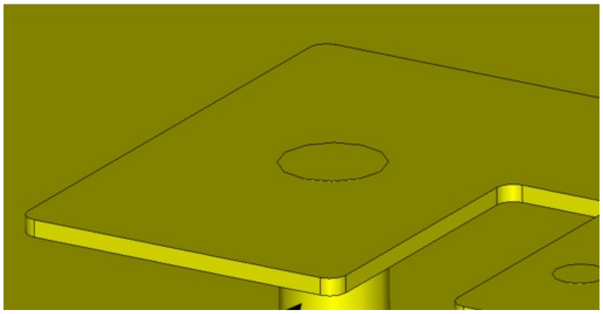
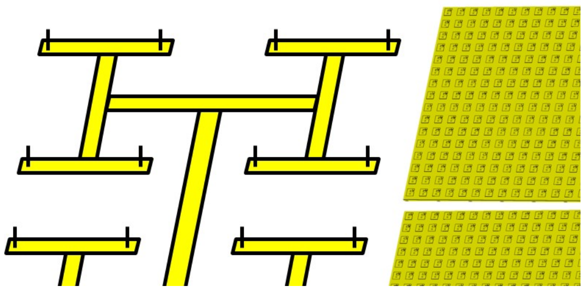


Fig. 2. Single element providing RHCP at Tx and Rx frequency bands with a single feed point.



(a) (b)

Fig. 3. (a) 1-to-16 waveguide power divider to excite each subarrays (a subarray is a 8×8 patch array fed by a stripline feed network). (b) The all-metal dual-frequency RHCP HGA for DTE/DFE. 32×32 patch array.

II. Antenna Description

A. *Antenna requirements*

To satisfy the dual-band communication link with NASA's Deep Space Network at the X-band, the antenna needs to meet stringent requirements across both uplink and downlink frequency bands with a sufficient thermal guard band.

The antenna should be circularly polarized. Its efficiency should be higher than 80% at both frequency bands to provide at least a gain of 36.0dBi and 37.1dBi at 7.19GHz and 8.425GHz, respectively. The antenna axial ratio should be better than 3dB. The antenna return loss should remain above 14dB.

It should survive and perform at 50K (~ -223°C) and high radiation levels. It should also be immune from electrostatic discharge (ESD). The antenna should also handle an input power of 100W continuous wave in vacuum. Finally, the antenna needs be flat and should fit in a confined volume of 82.5×82.5×3 cm^3.

It is important to note that the antenna pointing to Earth in azimuth and elevation is enabled by a mechanical gimbal.

B. *Antenna design*

Single element

The key innovation to support the needed requirements is the single element providing RHCP at both uplink and downlink frequency bands (Fig. 2). This element is single-fed, as shown in Fig. 2, which simplifies the feeding network and the antenna fabrication and assembly. This patch element is entirely made of aluminum and is grounded to the antenna ground through a structural post. This structural post does not affect the antenna performance as it is located where the current is null. The single element is optimized in an infinite array to obtain the required axial ratio and impedance. Once the performance of the single element is met, its performance in an array is verified.

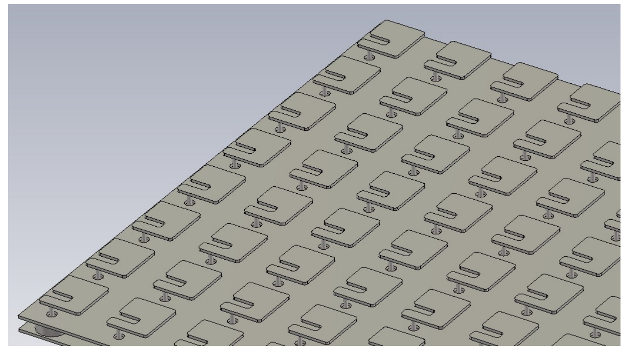


Fig. 4. All-metal 8×8 subarray.

DTE antenna: 32×32 patch array

The DTE antenna consists of 32×32 patch array (Fig. 3). The 32×32 patch array is composed of four panels. Each panel is made up of four subarrays (Fig. 3b). Each of the 8×8 patch subarray elements are fed using air stripline which is housed under the top ground plane. Each subarray is fed using WR-112 waveguides beneath the antenna as shown in Fig. 3a. Using waveguides to feed all 16 subarrays allows the antenna to support high input or transmitter power levels. For an input power of 100W, the power seen at the stripline input would be 6.25W. It also simplifies the matching network. A WR-112 waveguide to air-stripline transition was designed specifically for this antenna. The spacing between each patch element is $0.62 \cdot \lambda_0$ and was chosen to fit the antenna in the allocated volume. This simple, building block, antenna architecture compartmentalizes the design challenges that must be addressed and allows the designers to reuse solutions as needed. A gain of more than 36.0dBi and 37.1dBi is reached at uplink and downlink frequency bands, respectively.

8×8 subarray

The subarray is an 8×8 patch array fed using an air stripline feed network (Fig. 4). The air stripline is very low loss (i.e. less than 0.2dB). The thickness was chosen to have sufficient margin against multipaction (i.e. more than 20dB). One subarray is currently under fabrication. The reflection coefficient of the subarray is shown in Fig. 5. From 7GHz to 9GHz, the reflection coefficient is below -10dB. The radiation pattern is shown in Fig. 6. Excellent agreement was fund using CST MWS and HFSS for the reflection coefficient and the radiation pattern. The maximum insertion loss is assessed to be roughly 0.3dB which translates into 93% efficiency. The antenna directivity and gain are shown in Table I.

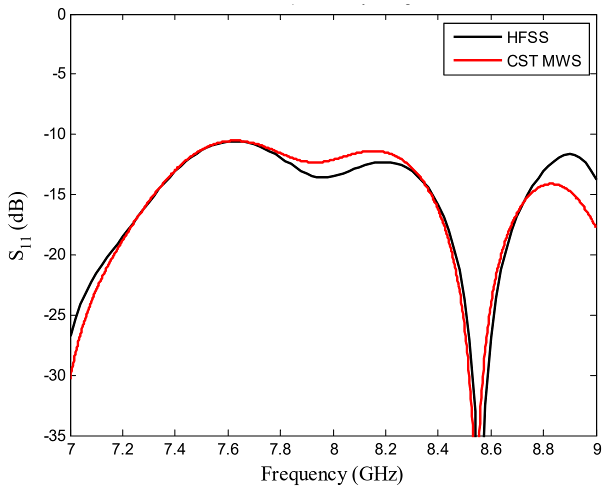
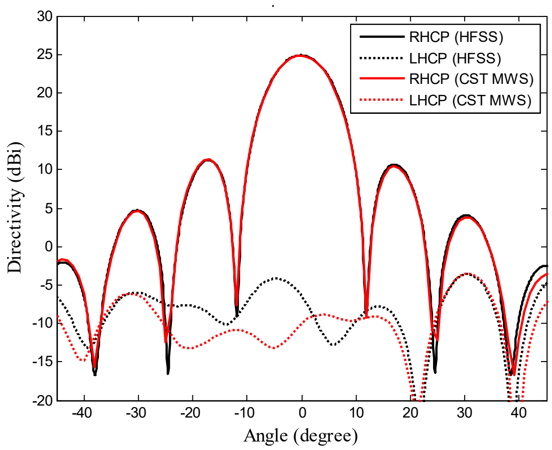
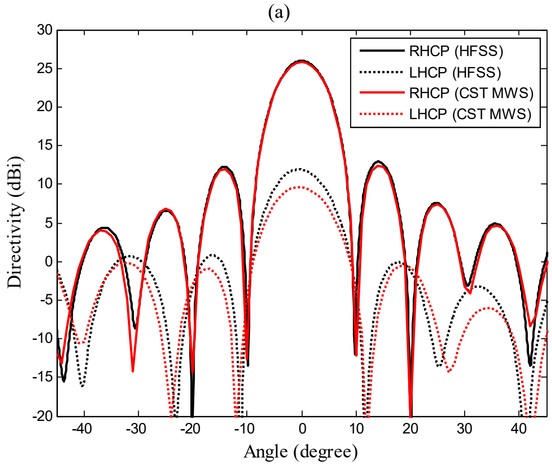


Fig. 5. Reflection coefficient of a potential Europa Lander subarray (8x8 patch subarray).



(a)



(b)

Fig. 6. Radiation pattern of a potential Europa Lander subarray (8×8 patch array) (a) at 7.19GHz and (b) 8.425GHz.

TABLE I. Calculated directivity and gain of the 8×8 subarray.

	Directivity (dBi)		**Gain (dBi)**	
Frequency (GHz)	CST MWS	HFSS	CST MWS	HFSS
7.19	24.8	24.9	24.6	24.8
8.425	25.9	26.0	25.6	25.9

III. CONCLUSION

The high gain antenna for a potential Europa Lander was introduced conceptually. It consists of 16 sets of 8x8 element patch subarrays. Low-loss air striplines are employed to feed the 8x8 patch elements within each subarrays. Each subarrays are fed using a 1-to-16 waveguide power divider.

The antenna can easily sustain the input power of 100W in vacuum and it was designed to survive the harsh environment of Europa (i.e. high radiation and ESD levels and low temperatures).

A prototype of the 8x8 subarray is currently under fabrication. Measurement results will be presented during the conference.

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REFERENCES

[1] NASA/JPL, *"Europa Lander study 2016 report, Europa Lander Mission"*, JPL D-97667, Feb. 2017.

[2] M. Bray, "A radial line slot array antenna for deep space missions," *2017 IEEE Aerospace Conference*, Big Sky, MT, 2017.

[3] D. González-Ovejero, G. Minatti, G. Chattopadhyay and S. Maci, "Multibeam by metasurface antennas," *IEEE Trans. Antennas Propag.*, vol. 65, no. 6, pp. 2923-2930, Jun. 2017.

[4] G. Minatti, M. Faenzi, E. Martini, F. Caminita, P. De Vita, D. González-Ovejero, M. Sabbadini, and S. Maci, "Modulated metasurface antennas for space: synthesis, analysis and realizations," *IEEE Trans. Antennas Propag.*, vol. 63, no. 4, pp. 1288–1300, Apr. 2015.

[5] P. Nayeri, K.-F. Lee, A. Z. Elsherbeni, and F. Yang, "Dual-band circularly polarized antennas using stacked patches with asymmetric U-slots," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 492–495, 2011.

[6] Nasimuddin, X. Qing, and Z. N. Chen, "A wideband circularly polarized stacked slotted microstrip patch antenna," *IEEE Antennas Propag. Mag.*, vol. 55, no. 6, pp. 84–99, 2013.

[7] F. Yang, X. Zhang, X. Ye, and Y. Rahmat-Samii, "Wide-band E-shaped patch antennas for wireless communications," *IEEE Trans. Antennas Propag.*, vol. 49, no. 7, pp. 1094–1100, 2001.

[8] K.-F. Tong and T.-P. Wong, "Circularly polarized U-slot antenna," *IEEE Trans. Antennas Propag.*, vol. 55, pp. 2382–2385, Aug. 2007.

[9] S. S. Yang, K. Lee, A. A. Kishk, and K. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Prog. Electromagnet. Res.*, vol. 80, pp. 45–61, 2008.

[10] N. Chamberlain, J. Chen, P. Focardi, R. Hodges, R. Hughes, J. Jakoboski, J. Venkatesan, M. Zawadzki, "Juno Microwave

Radiometer Patch Array Antennas," *IEEE Antennas and Propagation Society International Symposium*, APSURSI'09, 2009.